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Availability, use of, and satisfaction with green space, and children's mental wellbeing at age 4 years in a multicultural, deprived, urban area: results from the Born in Bradford cohort study

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Summary

Background It is unknown whether the quantity or quality of green space is more important for mental wellbeing. We aimed to explore associations between availability of, satisfaction with, and use of green space and mental wellbeing among children aged 4 years in a multi-ethnic sample.

Methods We did a 4-year follow-up assessment of participants in the Born in Bradford longitudinal cohort study, which recruited children and mothers at the city's main maternity unit from 2007 to 2011. The primary outcome was parent-reported mental wellbeing for children aged 4 years, assessed with the standardised Strengths and Difficulties Questionnaire. Total, internalising, and externalising behavioural difficulties and prosocial behaviour scales were computed (with higher scores indicating greater difficulties or more prosocial behaviour). Residential green space around participants' home addresses and distance to major green spaces were computed with the normalised difference vegetation index (NDVI). A subsample of participants completed additional questionnaires on measures of satisfaction with, and use of, local green spaces. Multiple regressions examined associations between green space and children's mental wellbeing and explored moderation by ethnicity (white British *vs* south Asian) and socioeconomic status.

Findings Between Oct 1, 2012, and June 30, 2015, 2594 mothers attended a follow-up appointment during which they completed a detailed questionnaire assessing the health of their child. 1519 (58%) participants were of south Asian origin, 740 (29%) of white British origin, and 333 (13%) of another ethnicity. Data on ethnicity were missing for two participants. 832 (32%) of 2594 participants completed additional questionnaires. Ethnicity moderated associations between residential green space and mental wellbeing ($p<0·05$ for total and internalising difficulties). After adjusting for all relevant variables, more green space was associated with fewer internalising behavioural difficulties (mean NDVI 100 m: β –2·35 [95% CI –4·20 to –0·50]; 300 m: –3·15 [–5·18 to –1·13]; 500 m: –2·85 [–4·91 to –0·80]) and with fewer total behavioural difficulties (100 m: –4·27 [–7·65 to –0·90]; 300 m: –5·22 [–8·91 to –1·54]; 500 m: –4·82 [–8·57 to –1·07]) only for south Asian children across all three buffer zones. In the subsample of participants, the effect of NDVI on wellbeing was rendered non-significant after controlling for satisfaction with, and use of, green space. Among south Asian children, satisfaction with green space was significantly associated with fewer total behavioural difficulties across all three buffer zones (β –0·59 [95% CI –1·11 to –0·07]), fewer internalising behavioural difficulties within 100 m (–0·28 [95% CI –0·56 to –0·003]) and 300 m buffer zones (–0·28 [–0·56 to –0·002]), and greater prosocial behaviour across all three buffer zones (0·20 [0·02 to 0·38]); no such associations were observed among white British children.

Interpretation Positive effects of green space on wellbeing differ by ethnicity. Satisfaction with the quality of green space appears to be a more important predictor of wellbeing than does quantity of green space. Public health professionals and urban planners need to focus on both quality and quantity of urban green spaces to promote health, particularly among ethnic minority groups.

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Introduction

Mental ill health is a major source of disease,[1] with costs estimated to be US$2·5 trillion globally.[2] Natural environments are important determinants of physical and mental health[3–5] and, with more than 50% of the global population and 73% of Europe's population[6] living in urban areas, urban green spaces have an important role in improving quality of life for urban dwellers. Despite a large body of evidence linking urban green spaces to mental health among adults, a systematic review has highlighted the paucity of evidence exploring associations between natural environments and

Research in context

Evidence before this study

We searched the Web of Science, MEDLINE, and PsycINFO databases up to Dec 12, 2017, using the following search terms: ("Green space") and ("child" or "preschool", both MeSH headings) and ("mental health" MeSH term or "strengths and difficulties" or "SDQ"). We also searched reference lists of previous systematic reviews on this subject. We included quantitative studies that calculated an objective measure of green space availability by use of geographical information systems data (for example, percentage of green space within a predefined buffer or satellite-derived estimates of green space density), samples of children aged younger than 16 years, and used the standardised Strengths and Difficulties Questionnaire (SDQ) as the primary outcome measure. We found eight studies examining associations between aspects of green space and wellbeing assessed by use of the SDQ, with inconsistent findings. None of these studies compared the relative contributions of quantity, quality, and use in associations between green space and wellbeing. Few studies explored whether associations were moderated by socioeconomic status and none explored variations by ethnicity. Limitations of the available literature included the inability to control for parental wellbeing.

Added value of this study

This study is, to our knowledge, the first to explore relative associations of quantity, quality, and use of green space with mental wellbeing in a multi-ethnic sample of children aged 4 years in a deprived urban area. We found that more green space was associated with fewer total and internalising behavioural difficulties in children of south Asian origin living in a deprived urban area in the UK, but found no such association for white British children. We also found that, compared with white British children, south Asian children spent less time playing outside in green spaces, and that their parents were less satisfied with their green spaces. We found that satisfaction with the quality of local green spaces was a more important predictor of wellbeing than either quantity or use of green space among south Asian parents. Unlike some previous studies, we found no evidence of moderation by socioeconomic status.

Implications of all the available evidence

Local green spaces can promote positive wellbeing in children. However, the quantity of green space is not in itself sufficient to promote health. Ethnic minority groups typically have reduced access to high quality green spaces compared with the general population, which heightens health inequalities. Urban planners and public health professionals should work together to increase the availability and quality of green spaces for marginalised communities through a combination of structural and community-based interventions.

children's mental health.[4] As mental ill health in childhood is an important predictor of mental health in adulthood,[7] ascertaining the potential of urban green spaces in promoting mental wellbeing among children is important.

Studies have reported mixed effects of urban green spaces on children's mental wellbeing,[8–15] as assessed by the Strengths and Difficulties Questionnaire (SDQ).[16] A limitation of these studies is that, with the exception of one,[10] none was able to control for the effect of maternal mental wellbeing on children's outcomes, a factor that has been shown to predict later distress among children.[17] Differences in measurement of green space exposure are also likely to have contributed to the mixed research findings. Many studies use area-based measures of green space, such as a percentage of green space within a predefined geographical unit[10] or the normalised difference vegetation index (NDVI), which estimates density of green vegetation within a predefined area.[11] However, these measures do not assess the actual or perceived quality of local green space and how it is used by local communities. Quality can be measured objectively through use of standardised audit tools[18] or by asking participants to rate attributes of environments according to a range of criteria.[19] The quality of green space has been shown to independently predict mental wellbeing in adults, in addition to indicators of quantity.[5,19] One study explored associations between objectively assessed quality, satisfaction with, and use of local green space in a multi-ethnic deprived community (Roberts H, Department of Psychology, University of Leeds [Leeds, UK] and Bradford Institute for Health Research, Bradford Teaching Hospitals NHS Foundation Trust [Bradford, UK], personal communication). Poorer quality green spaces assessed via park audits influenced perceived satisfaction with green spaces, suggesting that satisfaction can be a useful proxy for objective assessments of quality. Furthermore, quality of green spaces predicted subsequent use of these spaces. To fully investigate the differences in the associations between green space and health outcomes for different groups, it is important to have information about how these spaces are perceived and used. However, with some notable exceptions,[9,10] there is a paucity of literature in this area, and studies exploring the relative contribution of the availability of, satisfaction with, and use of green space on mental wellbeing among children are warranted.

An important debate in the literature involves identifying subgroups for whom interventions to promote green space availability and use might be most effective. Interventions such as increasing access to nature might function as a tool to reduce health inequalities by disproportionately benefiting those in greatest need.[20] Beneficial effects also appear to vary by

ethnicity, although results are mixed[21,22] and no studies have explored variations in the context of children's mental wellbeing. Reasons for ethnic differences are unclear, but minority groups might use green spaces less frequently than the general population because of dissatisfaction and perceived safety concerns.[23] These findings highlight the importance of including, in addition to measures of availability, measures of satisfaction with, and use of, green space in studies aiming to identify associations between green space and health.

We aimed to explore the associations between availability of, satisfaction with, and use of urban green space (subsequently referred to as green space) and mental wellbeing among children aged 4 years. We also aimed to explore whether or not ethnicity or socioeconomic status moderated any effects of green space.

Methods

Study design and participants

This study was nested within a follow-up subsample of the Born in Bradford cohort, a longitudinal study of 12 453 mothers recruited during pregnancy and 13 776 children at the City's main maternity unit between 2007 and 2011. Full methods have been previously published.[24] Bradford is the fifth largest metropolitan district in England, UK, and is characterised by high levels of ethnic diversity and deprivation.[24] 50% of the study cohort is of south Asian origin.

Participants provided written consent to long-term follow-up and to routine data linkage for health and education records. The present study reports data from respondents who participated in a follow-up assessment when their child was aged 4 years. The data reported came from information collected at baseline (during pregnancy), from bespoke questions asked during the 4-year assessment, and from routine data linkage. Ethical approval was obtained from the Bradford NHS Research Ethics Committee (reference 07/H1302/112).

Mothers attended a follow-up appointment during which they completed a detailed questionnaire assessing the health of their child. Appointments were offered in Mirpuri, Punjabi, or Urdu languages; 69% of appointments were conducted in English and 31% in Mirpuri, Punjabi, or Urdu. A subsample of respondents completed an additional detailed questionnaire on green space use and satisfaction. Because of resource constraints, the additional questionnaire was offered only to English-speaking participants.

Measures

The primary outcome was parent-reported mental wellbeing assessed with the standardised SDQ.[16] The SDQ contains 25 items assessing four core dimensions of difficulties, two of which are externalising (conduct problems and hyperactivity) and two are internalising (emotional problems and peer problems). The questionnaire also assesses one area of strength: prosocial behaviour (range 0–5, with higher scores indicating more prosocial behaviour towards others). The four difficulty domains can be summed to create a total difficulties score (range 0–40, with higher scores indicating greater difficulties); they can also be combined into the two broader internalising and externalising subscales (range 0–20 for both, with higher scores indicating greater difficulties).

We calculated measures of residential green space for each participant using the NDVI. To explore residential greenness, we calculated the NDVI within three straight line buffers of 100 m, 300 m, and 500 m around participants' geocoded home address. The NDVI ranges between –1 and 1, with higher values indicating more green vegetation. We used the Landsat 5 TM (USGS) remote sensing data at 30 m resolution to calculate NDVI values using the best available images between 2006 and 2011; images were mostly taken on June 10, 2006 (figure), with the exception of a small number of participants to the north of Bradford for whom a separate image was required and taken on Sept 28, 2011. We excluded major water bodies larger than 0·5 hectares (>5000 m²) because these values can skew the results of an otherwise green neighbourhood. Straight-line distances to major green spaces (>5000 m²) were calculated in metres.

A subsample of respondents was asked to rate satisfaction with, and use of, local green spaces. Green spaces were defined as public parks (including play areas specifically for children), sports playing fields, or other natural habitats (eg, woodland) comprising plants and other vegetation. To ascertain how often children used green spaces, we asked parents to report: how many days their child spent playing outside in green spaces per week in summer months and winter months, and how long on average their child spent playing outside in green spaces on these days (minutes per day). Responses were multiplied to create a weekly playing outside index for summer and winter. These indices were averaged to create an overall weekly playing outside index (minutes per week) as a proxy measure of time spent outside. Parents were then asked to report which green space they used most frequently in summer months and were asked how satisfied they were with its quality, with responses recorded on a five-point Likert-type scale ranging from 1 (very dissatisfied) to 5 (very satisfied), where 3 was a neutral response.

Ethnicity was self-reported at baseline with standard classifications.[25] Because of large numbers of two main ethnic groups, we split ethnicity into three groups: south Asian, white British, and other. The last category represents a diverse group including Bangladeshi, black-African, and mixed race individuals. When comparing results of findings by ethnicity, we show results for south Asian and white British groups only.

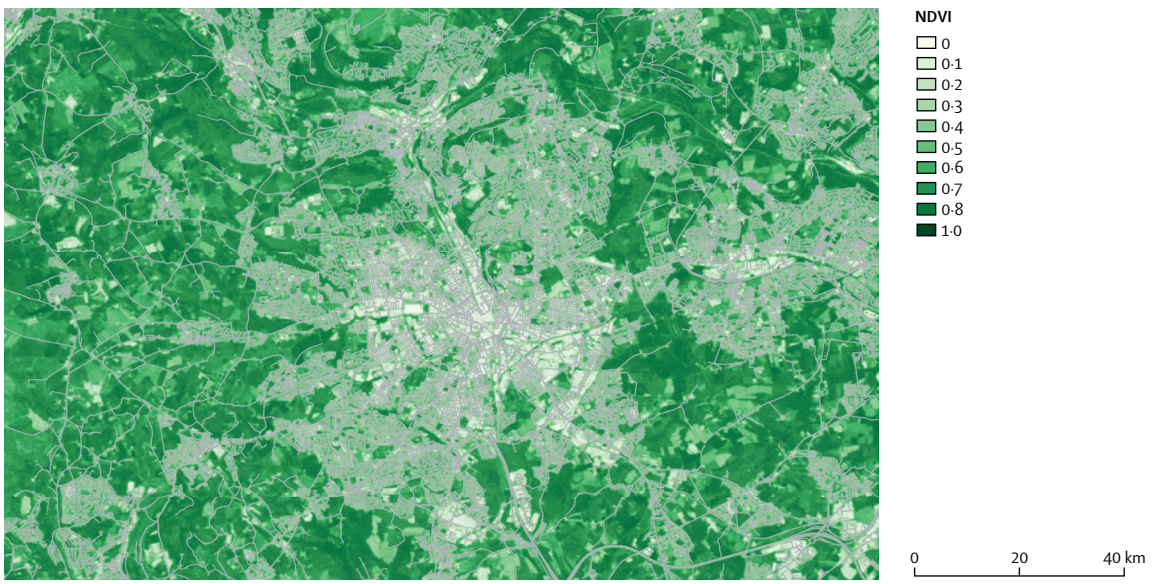

Figure: **Green space in Bradford, UK**
NDVI=normalised difference vegetation index. Source: Landsat 5 TM (USGS) remote sensing data at 30 m resolution (June 10, 2006).

We assessed individual and area-level indicators of socioeconomic status in line with previous literature on this subject.[22] At an individual level we recorded mothers' educational status as 1 (not reached high school diploma level, including those whose educational status was marked as unknown, a foreign qualification, or other), or 2 (high school diploma equivalent or higher). A measure of subjective poverty was included by use of the item "How well would you say you or you and your husband/partner are managing financially these days?". Response options "just about getting by", "quite difficult", "very difficult", and "does not wish to answer" were coded as 1 (struggling financially). Response options "living comfortably" and "doing alright" were coded as 2 (not struggling financially).

At an area level we included the Index of Multiple Deprivation (IMD)[26] as a measure of relative deprivation at a national level. The IMD is constructed from seven domains of deprivation (income, employment, education, health, crime, barriers to housing and services, and living environment) at a lower super output area (LSOA) level. The postcode of each mother's place of residence at registration was mapped to the LSOA and these were then matched to IMD 2015 scores. Given the high level of deprivation observed in the current sample (with 66% of the sample living in the most deprived quintile of deprivation relative to UK averages), we split IMD scores into local quintiles of deprivation (where 1 comprises the most deprived quintile within the sample and 5 comprises the least deprived).

Other variables were mother's age, mother's smoking behaviour, child's age, and mother's cohabitation status (married and living with partner, not married and living with partner, or not living with partner). Tertiles of household size were calculated for the total sample population and for each ethnic group (where tertile 1 represents smallest house sizes and tertile 3 represents largest house sizes). We constructed a dichotomous variable indicating whether the mother had a record of treatment for any common mental disorder (eg, anxiety or depression) during the previous year from their routine primary health-care data using a validated algorithm.[17]

Statistical analysis

We explored associations between measures of green space and children's total, externalising, and internalising SDQ scores, as well as the prosocial behaviour scale. Analyses were done in R, version 3.3.1.[27] Analyses were done for the total sample and separately for white British and south Asian groups for comparison. Mean (SD) values were calculated for parametric variables and median (IQR) values for non-parametric variables. Cronbach's alpha (a measure of internal scale reliability) was computed for the SDQ scales. Comparisons between the white British and south Asian groups were done with Welch's *t* tests and Mann-Whitney *U* tests for continuous variables and with χ^2 tests and Fisher's exact tests for categorical variables. Ten high outlying responses for minutes spent playing outside per week were identified. We ran a sensitivity analysis removing these outlying responses and results were not altered. These participants were thus retained. p values were also calculated to test for differences in characteristics between the total sample size and subsamples of participants who completed the additional green space questionnaire. p values less than 0·05 were considered significant.

	Total (N=2594)	White British (N=740)	South Asian (N=1519)	Other ethnicity (N=333)	p value*
SDQ					
Total difficulties	2591 (100%); 10 (6–14)	738 (100%); 8 (5–12)	1518 (100%); 11 (7–15)	333 (100%); 8 (5–12)	<0·0001
Internalising difficulties	2591 (100%); 3 (2–5)	738 (100%); 2 (2–6)	1518 (100%); 4 (2–6)	333 (100%); 3 (1–5)	<0·0001
Externalising difficulties	2591 (100%); 6 (4–9)	738 (100%); 5 (3–8)	1518 (100%); 6 (4–9)	333 (100%); 5 (3–7)	<0·0001
Prosocial behaviour	2590 (100%); 9 (7–10)	738 (100%); 9 (7–10)	1518 (100%); 9 (7–10)	332 (100%); 9 (7–10)	0·6
Green space					
NDVI					
100 m	2488 (96%); 0·36 (0·30 to 0·44)	665 (90%); 0·41 (0·35 to 0·48)	1505 (100%); 0·33 (0·29 to 0·41)	316 (95%); 0·39 (0·33 to 0·45)	<0·0001
300 m	2488 (96%); 0·38 (0·32 to 0·45)	665 (90%); 0·43 (0·36 to 0·49)	1505 (100%); 0·35 (0·32 to 0·42)	316 (95%); 0·39 (0·34 to 0·46)	<0·0001
500 m	2488 (96%); 0·40 (0·33 to 0·45)	665 (90%); 0·43 (0·37 to 0·51)	1505 (100%); 0·36 (0·32 to 0·43)	316 (95%); 0·39 (–0·34 to 0·46)	<0·0001
Distance to major green space, m	2487 (96%); 221 (108–406)	664 (90%); 211 (100–383)	1505 (100%); 231 (116–422)	316 (95%); 214 (97–381)	0·05
Demographics					
Age of child, years	2594 (100%); 4·5 (0·4)	740 (100%); 4·5 (0·4)	1519 (100%); 4·5 (0·4)	333 (100%); 4·5 (0·4)	0·4
Sex of child					
Male	1302 (50%)	386 (52%)	741 (49%)	175 (53%)	0·1
Female	1292 (50%)	354 (48%)	778 (51%)	158 (47%)	..
Age of mother, years	2594 (100%); 33·6 (5·5)	740 (100%); 33·9 (6·1)	1519 (100%); 33·4 (5·3)	333 (100%); 34·1 (5·5)	0·1
Cohabitation status					
Married and living with partner	2056 (79%)	383 (52%)	1418 (93%)	253 (76%)	<0·0001
Not married and living with partner	314 (12%)	168 (23%)	97 (6%)	48 (14%)	..
Not living with partner	224 (9%)	188 (25%)	4 (1%)	32 (10%)	..
Socioeconomic status of mother					
Maternal education					
A-level equivalent or higher	1058 (41%)	338 (46%)	550 (36%)	170 (51%)	<0·0001
Maximum of five GCSEs, unknown, foreign, or other	1530 (59%)	402 (54%)	965 (64%)	162 (49%)	..
Subjective poverty					
Struggling financially	817 (32%)	245 (33%)	485 (32%)	88 (26%)	0·6
Not struggling financially	1775 (68%)	495 (67%)	1034 (68%)	245 (74%)	..
Household size	2587 (100%); 5·3 (2·0)	738 (100%); 4·1 (1·2)	1516 (100%); 6·1 (2·2)	331 (100%); 4·5 (1·4)	<0·0001
Tertile 1	1071 (41%)	541 (73%)	341 (22%)	189 (57%)	..
Tertile 2	960 (37%)	172 (23%)	676 (45%)	111 (34%)	..
Tertile 3	556 (21%)	25 (4%)	499 (33%)	31 (9%)	..
IMD quintile					
Quintile 1	566 (22%)	334 (46%)	163 (11%)	69 (21%)	<0·0001
Quintile 2	492 (19%)	139 (19%)	283 (19%)	69 (21%)	..
Quintile 3	560 (22%)	85 (12%)	404 (27%)	70 (22%)	..
Quintile 4	444 (17%)	86 (12%)	320 (21%)	38 (12%)	..
Quintile 5	505 (20%)	88 (12%)	338 (22%)	79 (24%)	..

(Table 1 continues on next page)

	Total (N=2594)	White British (N=740)	South Asian (N=1519)	Other ethnicity (N=333)	p value*
(Continued from previous page)					
Health behaviours					
Mother smoking					
Yes	234 (9%)	166 (23%)	40 (3%)	28 (8%)	<0·0001
No	2353 (91%)	570 (77%)	1476 (97%)	305 (92%)	..
Mother treated for any common mental disorder from previous year					
Yes	328 (13%)	159 (22%)	141 (9%)	27 (8%)	<0·0001
No	2266 (87%)	581 (78%)	1378 (91%)	306 (92%)	..

Data are n (%) plus median (IQR) or mean (SD). SDQ=Strengths and Difficulties Questionnaire (higher scores indicate more difficulties, with the exception of the prosocial behaviour scale where higher scores indicate more prosocial behaviour). NDVI=normalised difference vegetation index (higher scores indicate greener environments). IMD=Index of Multiple Deprivation (lower scores indicate more deprived areas). For household size, tertile 1 represents the smallest household size, whereas tertile 3 represents the largest household size. Numbers of white British, south Asian, and other ethnicity groups do not total 2594 as there were missing data on ethnicity for two participants. *p values test differences between white British and south Asian groups. Mann-Whitney U tests were used for non-parametric data, *t*-tests for parametric data, and χ^2 tests for categorical data.

Table 1: **Characteristics of study participants by ethnic group (full sample)**

Unadjusted regression models were computed, then covariates were entered sequentially in logical blocks after ethnicity was first adjusted for in the total sample population: demographic covariates (child's age and sex, and mother's age and cohabitation status), socioeconomic covariates (maternal education, subjective poverty, household size, and IMD [quintiles were created for the total sample population and within each ethnic group]), and health behaviours (maternal smoking and record of any common mental disorder). Results are reported as β coefficients, which represent the mean change in the predicted value of outcome Y for a one-unit increase in exposure X, while holding all other variables constant. Analyses were calculated for all three buffer zones (100 m, 300 m, and 500 m). IMD quintiles and satisfaction with outdoor green space were entered as continuous variables. In the subsample of participants, we included data on satisfaction with, and use of, local green space as predictors of wellbeing after controlling for all other confounding variables. These analyses therefore allowed comparison of quantity (NDVI), quality (satisfaction with), and use of green spaces in association with children's wellbeing.

To explore effect moderation by ethnicity or socioeconomic status, we assessed inclusion of an interaction term between residential surrounding greenness and ethnicity, maternal education, or financial struggles by comparing fully adjusted models with and without the interaction term using likelihood ratio tests. Moderation by ethnicity was significant; therefore, we stratified the fully adjusted models by ethnic groups.

Role of the funding source

The funder of the study had no role in study design, data collection, data analysis, data interpretation, writing of the report, or the decision to submit the paper for publication. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Results

Data were collected between Oct 1, 2012, and June 30, 2015. The final sample comprised 2594 mothers; of these, 1519 (58%) were south Asian, 740 (29%) were white British, and 333 (13%) of another ethnicity (table 1). Data on ethnicity were missing for two participants. The mean age of the mothers was 33·6 years (SD 5·5) and the mean age of their child was 4·5 years (0·4). Cronbach's alpha was 0·75 for total difficulties, 0·62 for the internalising subscale, 0·70 for the externalising subscale, and 0·67 for the prosocial behaviour scale. NDVI was significantly higher (ie, residential spaces were greener) for white British mothers than for south Asian mothers across all three buffer zones (p<0·0001). Median distance from a major green space was 221 m (IQR 108–406) for all participants, and did not differ significantly between ethnic groups (p=0·05; table 1).

832 (32%) of 2594 participants completed the additional questionnaire on green space use and satisfaction; these mothers reported lower SDQ scores and higher NDVI scores than the overall study sample, fewer mothers were married and living with their partner, and a higher proportion had higher levels of education, and reported lower levels of deprivation (appendix). No differences were noted when comparing the white British subsample with those who did not complete the additional questionnaire. However, south Asian mothers in the subsample reported lower SDQ scores, higher NDVI scores at all three buffers, higher levels of education, fewer reports of financial struggles, and fewer household members, and a slightly greater numbers of families were in the quintile of least deprivation than south Asian mothers in the overall sample.

More residential green space, as assessed by the NDVI, was associated with fewer total, internalising, and externalising behavioural difficulties in unadjusted models across all buffer zones (appendix). However, after controlling for sociodemographics, ethnicity, maternal smoking, and maternal mental health, these effects were non-significant. No associations between NDVI and prosocial behaviour were observed. Distance to major green spaces was not associated with any outcomes after adjustment and is thus not reported further.

With regard to associations between residential green spaces (assessed with NDVI) and children's mental wellbeing, we found no moderation by socioeconomic status (maternal education or financial struggles; data not shown), but significant moderation of residential green space with total and internalising difficulties by ethnicity ($p<0·05$ for both across all buffer zones; data not shown). Table 2 reports stratified analyses for the two main ethnic groups within the sample. In the unadjusted and adjusted analyses, we saw no associations between residential green space (assessed by NDVI) and behavioural difficulties or prosocial behaviour for children of white British mothers. However, among south Asian participants, more residential green space was associated

See Online for appendix

	White British				South Asian			
	Total difficulties*	Internalising difficulties*	Externalising difficulties*	Prosocial behaviour†	Total difficulties*	Internalising difficulties*	Externalising difficulties*	Prosocial behaviour†
Unadjusted‡								
Mean NDVI 100 m	−0·11 (−4·3 to 4·1)	0·59 (−1·5 to 2·7)	−0·71 (−3·7 to 2·3)	0·49 (−0·98 to 2·0)	−5·90 (−9·2 to −2·6)	−3·21 (−5·0 to −1·4)	−2·68 (−4·8 to −0·53)	0·18 (−0·92 to 1·30)
Mean NDVI 300 m	−0·30 (−4·4 to 3·8)	0·63 (−1·4 to 2·6)	−0·92 (−3·8 to 1·9)	0·46 (−0·96 to 1·9)	−6·90 (−10 to −3·4)	−4·01 (−5·9 to −2·1)	−2·89 (−5·2 to −0·58)	0·59 (−0·58 to 1·80)
Mean NDVI 500 m	−0·47 (−4·5 to 3·5)	0·49 (−1·5 to 2·4)	−0·95 (−3·8 to 1·8)	0·43 (−0·95 to 1·8)	−6·42 (−9·9 to −2·9)	−3·65 (−5·6 to −1·7)	−2·77 (−5·1 to −0·45)	0·65 (−0·58 to 1·80)
Adjusted§								
Mean NDVI 100 m	−0·02 (−4·01 to 3·97)	0·61 (−1·37 to 2·59)	−0·63 (−3·43 to 2·16)	0·51 (−0·91 to 1·93)	−6·03 (−9·22 to −2·78)	−3·21 (−4·99 to −1·43)	−2·82 (−4·95 to −0·67)	0·32 (−0·76 to 1·39)
Mean NDVI 300 m	−0·36 (−4·22 to 3·51)	0·59 (−1·32 to 2·52)	−0·95 (−3·67 to 1·75)	0·45 (−0·93 to 1·82)	−6·99 (−10·47 to −3·52)	−3·99 (−5·89 to −2·09)	−3·01 (−5·31 to −0·71)	0·71 (−0·45 to 1·86)
Mean NDVI 500 m	−0·56 (−4·33 to 3·21)	0·47 (−1·40 to 2·35)	−1·04 (−3·68 to 1·61)	0·45 (−0·89 to 1·79)	−6·51 (−10·01 to −3·01)	−3·67 (−5·58 to −1·75)	−2·84 (5·52 to −0·53)	0·72 (−0·44 to 1·88)
Adjusted¶								
Mean NDVI 100 m	−0·70 (−4·58 to 3·17)	0·35 (−1·61 to 2·33)	−1·05 (−3·78 to 1·66)	0·7 (−0·71 to 2·11)	−4·54 (−7·92 to −1·16)	−2·49 (−4·35 to −0·64)	−2·05 (−4·29 to 0·20)	0·28 (−0·86 to 1·43)
Mean NDVI 300 m	−0·29 (−4·05 to 3·46)	0·62 (−1·29 to 2·53)	−0·92 (−3·55 to 1·72)	0·5 (−0·87 to 1·87)	−5·44 (−9·14 to −1·76)	−3·28 (−5·31 to −1·26)	−2·16 (−4·62 to 0·29)	0·74 (−0·51 to 1·99)
Mean NDVI 500 m	−0·09 (−3·77 to 3·58)	0·64 (−1·22 to 2·51)	−0·74 (−3·31 to 1·84)	0·47 (−0·87 to 1·81)	−4·99 (−8·74 to −1·23)	−2·95 (−5·01 to −0·88)	−2·04 (−4·54 to 0·46)	0·77 (−0·50 to 2·04)
Adjusted‖								
Mean NDVI 100 m	−0·67 (−4·54 to 3·19)	0·41 (−1·56 to 2·39)	−1·09 (−3·79 to 1·61)	0·71 (−0·71 to 2·12)	−4·27 (−7·65 to −0·90)	−2·35 (−4·20 to −0·50)	−1·93 (−4·17 to 0·31)	0·36 (−0·78 to 1·49)
Mean NDVI 300 m	−0·2 (−3·95 to 3·55)	0·61 (−1·30 to 2·52)	−0·81 (−3·43 to 1·81)	0·44 (−0·94 to 1·81)	−5·22 (−8·91 to −1·54)	−3·15 (−5·18 to −1·13)	−2·07 (−4·52 to 0·39)	0·81 (−0·44 to 2·05)
Mean NDVI 500 m	−0·01 (−3·68 to 3·66)	0·59 (−1·28 to 2·47)	−0·6 (−3·17 to 1·96)	0·39 (−0·95 to 1·73)	−4·82 (−8·57 to −1·07)	−2·85 (−4·91 to −0·80)	−1·98 (−4·47 to 0·52)	0·86 (−0·41 to 2·18)

Data are β (95% CI). NDVI=normalised difference vegetation index (higher scores indicate greener environments). *Higher scores indicate more difficulties. †Higher scores indicate greater prosocial behaviour. ‡Model 1: white British, n=663, south Asian, n=1504. §Model 2: adjusted for child age, child sex, maternal age, and cohabitation status. White British, n=663; south Asian, n=1504. ¶Model 3: adjusted for demographics plus maternal education, subjective poverty, household size, and Index of Multiple Deprivation (IMD). White British, n=657; south Asian, n=1489. ||Model 4: controlled further for deprivation plus maternal smoking, and mother's treatment for common mental disorder in previous year. White British, n=653; south Asian, n=1486.

Table 2: **Associations between NDVI and wellbeing in white British and south Asian groups (full sample)**

	Total		White British		South Asian		Other ethnicity		p value*
	N	Mean (SD)	N	Mean (SD)	N	Mean (SD)	N	Mean (SD)	
Minutes per week spent outside in winter	831	95·75 (186·56)	336	130·68 (214·07)	365	58·12 (129·50)	130	104·69 (224·38)	0·001
Minutes per week spent outside in summer	831	372·07 (358·33)	336	401·71 (369·45)	365	357·44 (363·16)	130	336·52 (308·83)	0·03
Satisfaction with green space	805	4·04 (1·02)	328	4·16 (1·00)	352	3·93 (1·02)	125	4·05 (1·05)	0·001

One participant had missing data for time spent playing outside; 27 participants had missing data for reported satisfaction with green space. *p values tested differences between white British and south Asian groups with Mann-Whitney *U* tests.

Table 3: **Satisfaction with, and use of, green space by ethnic group (subsample)**

with fewer behavioural difficulties across all three buffer zones in both unadjusted and adjusted models (table 2). We repeated analyses among south Asian participants, exploring externalising and internalising subscales and the prosocial scale separately. After adjusting for all relevant variables (model 4), we found that the impact of green space was only apparent for internalising behavioural difficulties, and not for the other subcomponents, across all three buffer zones (table 2).

We repeated stratified analyses within the subsample of respondents who completed additional questionnaires. Satisfaction with, and use of, green space varied by ethnic group (table 3). White British children spent significantly more time outside than south Asian children or children in the "Other ethnicity" category, and parents of white British children also reported significantly higher levels of satisfaction with their local green space than did those from other ethnic groups (p=0·001; table 3). In this subsample, a significant negative association was observed between green space and internalising behavioural difficulties only among children of south Asian mothers, with increasing green space associated with fewer internalising behavioural difficulties (appendix). This association was strongest in the unadjusted models (100 m: β –4·05 [95% CI –7·27 to –0·83]; 300 m: –4·96, [–8·38 to –1·54], 500 m: –4·60 [–8·06 to –1·14]; appendix). Significant effects remained after adjustment for demographics (model 2) across all three buffer zones. When controlling further for deprivation (model 3), and maternal smoking and mental health (model 4), significant associations were found only for the 300 m and 500 m buffer zones (appendix).

In the final model, inclusion of time spent outside and satisfaction with green space rendered the influence of NDVI non-significant across all buffer zones. Within the south Asian subsample (n=344), satisfaction with local green spaces was associated with significantly fewer internalising behavioural difficulties within 100 m (table 4) and 300 m buffer zones (β –0·28 [95% CI –0·56 to –0·002]). Satisfaction with local green spaces was also associated with lower total behavioural difficulties across all three buffer zones (β –0·59 [95% CI –1·11 to –0·07]) and greater prosocial behaviour across all three buffer zones (0·20 [0·02 to 0·38]; table 4). We found no associations between satisfaction with green spaces and externalising behavioural difficulties across any buffer zones (data not shown). Finally, time spent outdoors had no effect on total, externalising, and internalising behavioural difficulties or on prosocial behaviour (table 4; only 100 m buffer results reported). Among the white British respondents, satisfaction with and use of green spaces were not associated with any measure of difficulty or prosocial behaviour (data not shown).

Discussion

We found a significant association between availability of green space (assessed by the NDVI) and both total and internalising behavioural difficulties among south Asian children living in a deprived urban area in the UK, but not among white British children. When satisfaction with and use of green space were included in our analyses, only satisfaction was significantly associated with mental wellbeing. Reported satisfaction with green space was independently predictive of internalising difficulties, total difficulties, and prosocial behaviour among south Asian children. Finally, we found that most of our study sample lived close to green spaces, and we found no associations between distance to green space and mental wellbeing.

Unlike some previous studies,[8,22] we found no evidence of moderation of effects by socioeconomic indicators such as maternal education or subjective poverty. However, the present study was situated in a highly deprived location in the UK, and this lack of variability might have contributed to an inability to identify any differences by socioeconomic status. Issues of residual confounding due to our inability to control, for example, for income or social class might also have contributed to the findings.

Moderation by ethnicity was apparent, with associations between green space and children's mental wellbeing observed only among south Asian children. We found that south Asian families faced a triple count of inequity in relation to green space. Not only did NDVI scores indicate that south Asian families had less residential

green space than their white British counterparts, they also reported less satisfaction with their green spaces, and that their children spent less time playing in green spaces. Furthermore, when satisfaction with green space was included in our analyses, it rendered the association of residential greenness non-significant. Satisfaction with green space was independently predictive of south Asian children's mental wellbeing after controlling for demographics, socioeconomic status, maternal health behaviours, and maternal mental wellbeing. This is an important finding, suggesting that the quality, in addition to quantity, of green space is important for health. Some authors suggest that quality of green space can act as a moderating factor, meaning that associations between quantity of green space and health outcomes are stronger when quality is higher.[28] We were unable to explore this association in our study as there was a mismatch in specificity for our quality indicator (satisfaction with a specific local green space) and our measure of quantity (NDVI in pre-specified buffer zones around residential addresses). Future research should aim to explore the potential moderating role of the quality of green space in association with health outcomes (ie, whether associations between wellbeing and quantity of green space are stronger when they are of higher quality than when they are of lower quality).

Internationally, evidence suggests that deprived groups have less access to green spaces than do less deprived groups.[29] These inherent inequalities are further exacerbated if the quality of available green spaces in marginalised communities is worse than that of non-marginalised communities. Within this setting, a study explored how the quality of local parks was linked to satisfaction and use (Roberts H, Department of Psychology, University of Leeds [Leeds, UK] and Bradford Institute for Health Research, Bradford Teaching Hospitals NHS Foundation Trust [Bradford, UK], personal communication). The authors found that ratings of satisfaction were predicted solely by structural park features relating to quality such as the presence of amenities (eg, presence of toilets, benches, and shelters) and incivilities within the park (eg, presence of litter or evidence of antisocial behaviour) rather than by ethnic or socioeconomic characteristics of respondents. Poor quality parks and green spaces can discourage use by marginalised communities. Fears about safety and antisocial behaviour, and concerns about cleanliness and maintenance, are key barriers to green space use.[30,31] Policy makers need to recognise these inequities and work to improve the perceptions of local green spaces, in addition to prioritising continued investment for maintenance and improvement of these spaces. Effective interventions will take into account the needs and preferences of all groups who use green spaces to ensure that these spaces are acceptable to all, and to increase community ownership of local space. Co-design will be central to this process, and although evaluations of these types of interventions are rare, evidence is available to suggest that co-designing interventions with local communities can result in increased quality of,[32] and use of,[33] green spaces. Implementation of system-wide changes to improve local environments will be challenging and will require concerted multi-sector efforts and cooperation from health, public policy, and urban planning professionals, and community perspectives in order to be successful.[34,35]

	Total difficulties*	Internalising difficulties*	Externalising difficulties*	Prosocial behaviour†
NDVI	−1·63 (−8·20 to 4·94)	−2·03 (−5·56 to 1·50)	0·39 (−4·03 to 4·82)	−1·03 (−3·31 to 1·24)
Child's age	−0·57 (−2·08 to 0·94)	−0·63 (−1·44 to 0·18)	0·06 (−0·95 to 1·07)	0·11 (−0·41 to 0·63)
Child's sex				
Male	..	..	..	..
Female	−0·58 (−1·53 to 0·47)	0·10 (−0·46 to 0·67)	−0·68 (−1·39 to 0·02)	0·43 (0·06 to 0·79)
Mother's age	−0·02 (−0·12 to 0·08)	−0·01 (−0·06 to 0·05)	−0·01 (−0·08 to 0·05)	0·01 (−0·03 to 0·04)
Mother's cohabitation				
Married and living with partner	..	..	..	..
Not living with partner	−1·24 (−3·37 to 0·89)	−0·63 (−1·77 to 0·52)	−0·61 (−2·05 to 0·82)	0·34 (−0·40 to 1·07)
Not married and living with partner	0·99 (−8·71 to 10·69)	3·15 (−2·06 to 8·37)	−2·16 (−8·69 to 4·37)	2·07 (−1·28 to 5·43)
Mother's education				
A-level equivalent or higher	..	..	..	..
Maximum of five GCSEs, unknown, foreign, or other	1·50 (0·41 to 2·58)	0·65 (0·07 to 1·24)	0·84 (0·11 to 1·57)	−0·01 (−0·38 to 0·37)
Subjective poverty				
Not struggling financially	..	..	..	..
Struggling financially	0·74 (−0·50 to 1·98)	0·37 (−0·30 to 1·03)	0·37 (−0·46 to 1·21)	0·11 (−0·32 to 0·54)
Number of members in household	−0·05 (−0·35 to 0·22)	0·03 (−0·11 to 0·18)	−0·09 (−0·27 to 0·09)	0·03 (−0·32 to 0·54)
IMD	−0·08 (−0·48 to 0·32)	−0·01 (−0·23 to 0·20)	−0·07 (−0·34 to 0·20)	−0·07 (−0·21 to 0·07)
Mother's smoking				
No	..	..	..	..
Yes	0·10 (−2·63 to 2·83)	−0·19 (−1·66 to 1·28)	0·29 (−1·55 to 2·13)	−1·00 (−1·94 to −0·05)
Mother had mental disorder in previous year				
No	..	..	..	..
Yes	0·99 (−0·75 to 2·73)	0·81 (−0·13 to 1·74)	0·18 (−0·99 to 1·35)	0·32 (−0·28 to 0·92)
Time spent outside (min)	0·0000 (−0·003 to 0·002)	−0·001 (−0·002 to 0·001)	0·001 (−0·001 to 0·002)	0·0005 (−0·0004 to 0·001)
Satisfaction with green space	−0·59 (−1·11 to −0·07)	−0·28 (−0·56 to −0·003)	−0·31 (−0·66 to 0·04)	0·20 (0·02 to 0·38)

Data are β (95% CI). NDVI=normalised difference vegetation index. IMD=Index of Multiple Deprivation. Only 100 m data reported for brevity; pattern of findings the same for 300 m buffer zone. *Higher scores indicate more difficulties. †Higher scores indicate greater prosocial behaviour.

Table 4: **Fully adjusted model for south Asian parents in the subsample (complete datasets, n=344)**

Our study had various strengths. To our knowledge, this study is the first to explore the relative contribution of the availability of, satisfaction with, and use of green space on children's mental wellbeing. This study was done within a deprived urban area with a multi-ethnic group of participants, and thus the findings are likely to be transferable to other multi-ethnic urban settings in the UK. We were able to control for an extensive array of potential confounding variables, including the effect of maternal mental distress on children's wellbeing, to disentangle the independent effects of green space on health in this group.

There are, however, several limitations. We used a validated, parent-reported measure of children's wellbeing; however, parental self-reporting could be subject to bias, including response bias. For example, a study found that associations between green space and wellbeing differed depending on whether parents or teachers were the primary informant.[9] Future research should aim to replicate these findings with different tools to assess mental wellbeing within children. As mentioned above, our study sample was predominantly of south Asian origin and comprised individuals living within a highly deprived area.[24] Therefore, our findings might not be generalisable to other more affluent and less ethnically diverse areas of the UK. Although we assessed the extent to which children played outside in green spaces, this outcome was self-reported by parents and potentially subject to response bias. Additionally, bias in responses to questions on green space satisfaction and use might have been introduced because the additional subsample questionnaire was only available to English speakers. We were unable to control for more general physical activity within our analyses. Although we assessed a wide range of potential confounders, other unmeasured variables could have contributed to residual confounding. Our measure of green space was calculated with NDVI scores from two images assessed 5 years apart (which were selected as they had minimal cloud cover). This approach might have introduced bias in our assessment of green space; however, previous research has found NDVI to be highly stable across this time period in the current setting.[21] Finally, our measure of green space satisfaction was based on respondents' frequently used parks rather than general neighbourhood green space, and we did not include objective audit assessments of the quality of local parks. Future research should aim to include both objective and subjective assessments of quality when exploring associations with health outcomes, and should explore whether satisfaction with specific frequently used green spaces is more important for wellbeing than perceptions of the neighbourhood as a whole.

In conclusion, the quality, in addition to quantity, of green space might be important for the mental wellbeing of ethnic minority groups. Provision of green space alone is unlikely to produce health benefits for these groups. Multi-sector approaches combining health professionals, urban planners, policy makers, and communities are needed to develop new and creative solutions to improve the quality of local green spaces, and to increase satisfaction with green spaces among marginalised communities.

Contributors

RRCM, MN, JW, KEP, and CJG conceived the study. RRCM drafted the report. TCY did the analysis and drafted the report with RRCM. RRCM, JW, KEP, HR, and DA-P were responsible for data collection and contributed to the analysis. All authors revised the report and provided intellectual input. All authors approved the final manuscript.

Declaration of interests

We declare no competing interests.

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